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SMALL-SCALE SPATIAL VARIATION OF WATER VAPOR IN THE ATMOSPHERE

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JANUARY 1988

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Dew points at nearby stations were compared. Stations close to each other did not necessarily exhibit the double oscillation of dew point to the same extent. The afternoon minimum could be lower than the morning minimum at one station while it was small or absent at nearby stations. Distance between sites was not found to be a strong indicator of degree of similarity between stations within the range 40-200 km. It was concluded that elevation, urbanization, and proximity to bodies of water were important determinants of atmospheric water vapor content.

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I. INTRODUCTION

Knowledge of the amount of water vapor in the atmosphere is important because this vapor absorbs energy throughout the electromagnetic spectrum. Extinction is so large at submillimeter wavelengths that it may be a problem along paths as short as one kilometer in an atmosphere with high absolute humidity [1]. Water vapor has some absorption bands at visible wavelengths where extinction is small but may not be negligible over long distances [2]. Extinction at infrared wavelengths is intermediate between these two extremes.

The amount of water vapor in the atmosphere is calculated from a relationship where the primary dependence is upon dew point. A slight dependence upon absolute temperature also exists. When dew points at two nearby stations are compared, the percent difference in absolute temperature is normally within about 2 percent at the level of the instrument shelter. Therefore, the difference of dew point indicates the difference in water vapor content.

It should be noted that the capacity of the atmosphere to hold water increases almost exponentially with temperature. Consequently, the water vapor content of the air varies greatly from place to place. Cold, dry air contains a small fraction of a percent of water vapor, but warm, moist air sometimes contains approximately 4 percent. Air at 20 °C can hold approximately 100 times as much water vapor as air at -40 °C. Maximum vapor content at -40 °C is only 0.1757 grams per cubic meter, and at 0 °C it is 4.847 grams per cubic meter. Air at 30.0 °C has a saturation absolute humidity of 30.4 grams per cubic meter [3]. When dew points at nearby stations are above 22 °C, and they differ by 1.0 °C, the difference of absolute humidity is at least 1.0 gram per cubic meter.

The classical pattern of diurnal variation of dew point is much more complicated than the pattern of temperature variation [4]. A minimum dew point coincides with the minimum temperature in the morning. Evaporation of water vapor from the ground after sunrise is accompanied by a decrease in stability with surface heating. Initially this decrease is small enough that the upward transfer of water vapor is confined to a shallow layer near the ground. Accumulation in this layer produces a maximum of water vapor between 0800 and 1000 hours local time. Continued surface heating produces so much thermal instability that vertical exchange distributes available water vapor through a very deep layer, and the ground becomes dry. A second minimum dew point occurs near the time of the maximum air temperature. Convection diminishes in late afternoon and early evening, and a second maximum dew point occurs a few hours after sunset. During the night there is a flux of water vapor from the air to the cooler ground, and the dew point of the air decreases until sunrise.

The similarity between nearby stations should be stronger in the afternoon when convection is more vigorous. With extensive vertical mixing and general increase in turbulence, small-scale variations caused by inhomogeneities in the underlying surface are often smoothed out.

The present study to see how much the atmosphere resembles the expected pattern is divided into two parts. The first part compares standard meteorological data from nearby sites. The second part consists of an analysis of special measurements taken in the Tennessee Valley in the summer of 1986.

II. STANDARD DATA

Periods of data were chosen on the basis of availability from the US Air Force Environmental Technical Applications Center (ETAC). The section in Asheville, North Carolina supplied data on magnetic tape with the standard TDF14 format.

A. Washington, District of Columbia

A long period of record was available for Washington National Airport, but no data were available from Dulles International Airport until 1962. Only three-hourly observations were used because hourly observations were on the tapes for only part of the period.

Figure 1 shows the diurnal variation of mean dew point during winter (December, January, and February) for the winters 1962-1963 through 1980-1981. Dew points were higher at Washington National Airport than at Dulles International Airport throughout the day. Urban effects such as combustion of motor vehicle fuel may contribute to increased absolute humidity [5] in the much more urbanized environment around Washington National Airport. However, in this case the location along the Potomac River is probably the more important factor.

The largest difference between the two stations occurred at 1200 Greenwich Mean Time (GMT) (0700 EST) when the difference was 1.17 °C. At typical winter morning temperatures and with the dew points in the figure, this represents a difference of about 0.3 grams per cubic meter of water vapor.

The smallest difference in dew point was 0.34 °C at 2100 GMT (1600 EST). This represents a difference of about 0.1 gram per cubic meter.

Expectations discussed in the introduction were only partially met. The much smaller difference in the afternoon was anticipated. On the other hand, these three-hourly means do not show the double cycle which is often observed in the atmosphere.

Figure 2 illustrates mean diurnal changes of dew point in the spring months (March, April, and May) during the years 1963 through 1981. The largest and smallest differences were 0.89 °C at 0900 GMT (0400 EST) and 0.23 °C at 0000 GMT (1900 EST). The corresponding mean differences of absolute humidity were 0.4 and 0.1 grams per cubic meter.

There was evidence of the double oscillation of dew point at Washington National Airport in spring. Minima of 4.51 °C and 4.77 °C occurred at 0900 GMT (0400 EST) and 0000 GMT (1900 EST), respectively. Maxima of 5.02 °C and 5.36 °C occurred at 0300 GMT (2200 EST) and 1800 GMT (1300 EST). These times were somewhat displaced from the expected times. Hourly data might have shown closer agreement.

Summer (June, July, and August) during the years 1963-1981 had a double oscillation of dew point at both stations in Washington, DC. Figure 3 shows that diurnal minima at both stations occurred at 0900 GMT (0400 EST) and at 2100 GMT (1600 EST). Both had morning maxima at 1500 GMT (1000 EST).

Dulles had a mean dew point of 17.83 °C at 0000 GMT (1900 EST) when the mean was 17.80 °C at Washington National. The largest difference was 1.42 °C at 0900 GMT (0400 EST), or a difference of 1.2 grams per cubic meter of water vapor. This was a difference of approximately 8 percent. Another interesting fact to note is that the afternoon minimum at Washington National was only slightly higher than the morning minimum. These two dew points were 17.66 °C and 17.72 °C.

The differences between dew points at Washington National and at Dulles were largest in fall (September, October, and November). Figure 4 for the years 1963-1981 shows that the difference between mean dew points at 0900 GMT (0400 EST) was 1.93 °C. The smallest difference was 0.72 °C at 1500 GMT (1000 EST). Corresponding absolute humidity differences were about 1.0 gram per cubic meter and 0.4 grams per cubic meter.

Both stations showed a double oscillation in fall, but the diurnal change was much larger at Dulles. The mean dew points at Dulles were 6.59 °C at 1200 GMT (0700 EST) and 8.42 °C at 1500 GMT (1000 EST). The afternoon minimum at Dulles was 7.79 °C, which was much higher than the minimum in the morning. At Washington National the afternoon minimum was only 0.18 °C higher than the morning minimum.

B. New York City

Temperatures and dew points were available for Kennedy International Airport, La Guardia, and Central Park for the years 1965-1981 except for the 1975-76 winter when dew points from Central Park were missing. The diurnal variations of mean dew point are shown in Figures 5 through 8. The graph for winter does not include Central Park because of the missing data.

Kennedy had higher mean dew points than the other stations throughout the diurnal cycle for all four seasons for 1965-1981. The differences between mean dew points at Kennedy and La Guardia were larger in the afternoon than in the morning throughout the year. In spring and fall dew points at Central Park and La Guardia were very close to each other. In summer dew points at Central Park were 0.5 °C higher than those at La Guardia in the afternoon.

The mean diurnal variation at La Guardia in summer was unusual compared to other diurnal variations discussed in this report. The afternoon minimum at La Guardia in summer was very broad, and dew points were lower in the afternoon than in the morning. The mean dew point at 0900 GMT (0400 EST) was 15.58 °C in summer at La Guardia. This was higher than the means at 1800 GMT, 2100 GMT, and 0000 GMT when the respective dew points were 15.51 °C, 15.47 °C, and 15.52 °C. Because of this unusual diurnal variation at La Guardia, the difference between Kennedy and La Guardia was much larger in the afternoon than at the other hours in summer. The largest difference was 1.40 °C at 2100 GMT (1600 EST). The smallest difference was 0.73 °C at 1500 GMT (1000 EST).

The double cycle in other dew-point observations at New York was less apparent. It did not appear at all in winter at either Kennedy or La Guardia, and in spring the afternoon minimum was weak at these two stations. The afternoon minimum was barely discernible at Central Park in spring and summer.

The summer variation at Kennedy had a broad morning minimum and an afternoon minimum displaced to early evening. The diurnal variation was small, but the double cycle was well defined at La Guardia and Central Park in fall. The afternoon minimum at Kennedy was poorly defined in fall. These observations from New York are consistent with those from Washington, DC, in indicating that the double oscillation of dew point is most prominent in the diurnal cycles for summer and may be entirely absent in winter.

III. COHMEX DATA

The Cooperative Huntsville Meteorological Experiment (COHMEX) provided a unique data base of measurements from spring and summer 1986. COHMEX consisted of three parts: (1) Satellite Precipitation and Cloud Experiment (SPACE); (2) Microburst and Severe Thunderstorm (MIST) program; and (3) FAA-Lincoln Laboratory Operational Weather Study (FLOWS).

The present study analyzed a subset of data from the SPACE. This subset consisted of data from the second generation portable automated surface mesonet (PAM II) system. This system was designed and built by the National Center for Atmospheric Research (NCAR). Additional information about SPACE may be found in the experiment design document Satellite Precipitation and Cloud Experiment [6].

A. Site Information

Table 1 contains the latitude, longitude, and elevation of each site which was used in the study. The station numbers were obtained from the magnetic tape. They do not correspond to numbers in the experiment design document [6], and some site information has been updated since the publication of this document. During the period of record of this investigation, stations 8, 9, and 10 had so much bad data that they were eliminated from the study.

Table 2 shows the computed distances between sites. The shortest distance between any pair of stations was the 47.95 km between stations 1 and 11. The longest distance was the 189.08 km between stations 2 and 7.

B. Mean Dew Points

Table 3 contains eight-day mean dew points for each hour of the day. The period of record was 0000 GMT, 1 June 1986, to 2359 GMT, 8 June 1986. Observations were originally recorded as one-minute means, and 60 of these were recorded for each hour. Therefore, each dew point in Table 3 represents a mean which was computed from 480 one-minute means. The means in the table are for the hour ending at the GMT listed in column 1, i.e., the mean for hour 12 represents data from 1101-1200 GMT.

Maxima and minima did not occur at precisely the same time at every station. Lowest dew points in the diurnal cycle occurred from the hour ending at 0900 GMT (0400 CDT or 0300 CST), to the one ending at 1100 GMT (0600 CDT). These morning minima were in the range 17.97 °C to 19.53 °C. Highest dew points occurred during the hours ending at 2300 GMT (1800 CDT) or 0000 GMT (1900 CDT).

The mean dew points for the eight days at stations 3, 6, and 11 were plotted in Figure 9. The double cycle was most evident at station 11 where a relative minimum occurred in the afternoon in the hour 2001-2100 GMT (1501-1600 CDT). The afternoon minimum was less pronounced and earlier at the other two stations in Figure 9. Minima in the morning were lower than the relative minima in the afternoon at each site for which data were included in Table 3.

C. Differences Between Stations

Tables 4 through 11 show the mean differences between dew points at all pairs of stations. The 24 hours were classified into eight periods of three hours each. Station numbers are listed in column 1 and along the top row of each table. The dew point at the station represented by the number in column 1 was subtracted from the dew point at the station which has its number listed in the top row.

The dew point at station 6 was lower than the dew points at all other stations in every one of Tables 4 through 11. This was expected because station 6 has a much higher elevation than any other station, and dew points decrease with height in the atmosphere the majority of the time [7]. Figures 10 through 17 are scatter diagrams in which difference in elevation has been plotted versus the difference in dew point. The dew point at the lower elevation was subtracted from the dew point at the higher elevation. Several positive differences occurred for differences of elevation less than 100 m, and a few positive differences were even associated with elevation differences more than 100 m. All differences would have been negative if the average decrease of dew point with elevation had been the only factor influencing results.

Figures 18 through 21 represent the differences of dew point versus distance between stations for four of the eight time periods. The excessive scatter indicates that distance between stations is relatively unimportant in determining dew point differences within the time and range of distances included in this study.

Figure 22 compares differences between dew points at pairs of stations during different times of day. Dew point differences below the diagonals in Table 4 and Table 7 were compared. The abscissa represents differences during the time period 0800-1059 GMT (0300-0559 CDT). The ordinate represents differences during the period 2300-0159 GMT (1800-2059 CDT). The dew point differences obviously had a similar pattern in the early morning and early evening hours.

IV. CONCLUSION

Local effects influence differences between dew points at different sites more than distance between sites when distances are less than 200 km. These local influences include elevation, urban effects, and proximity to water.

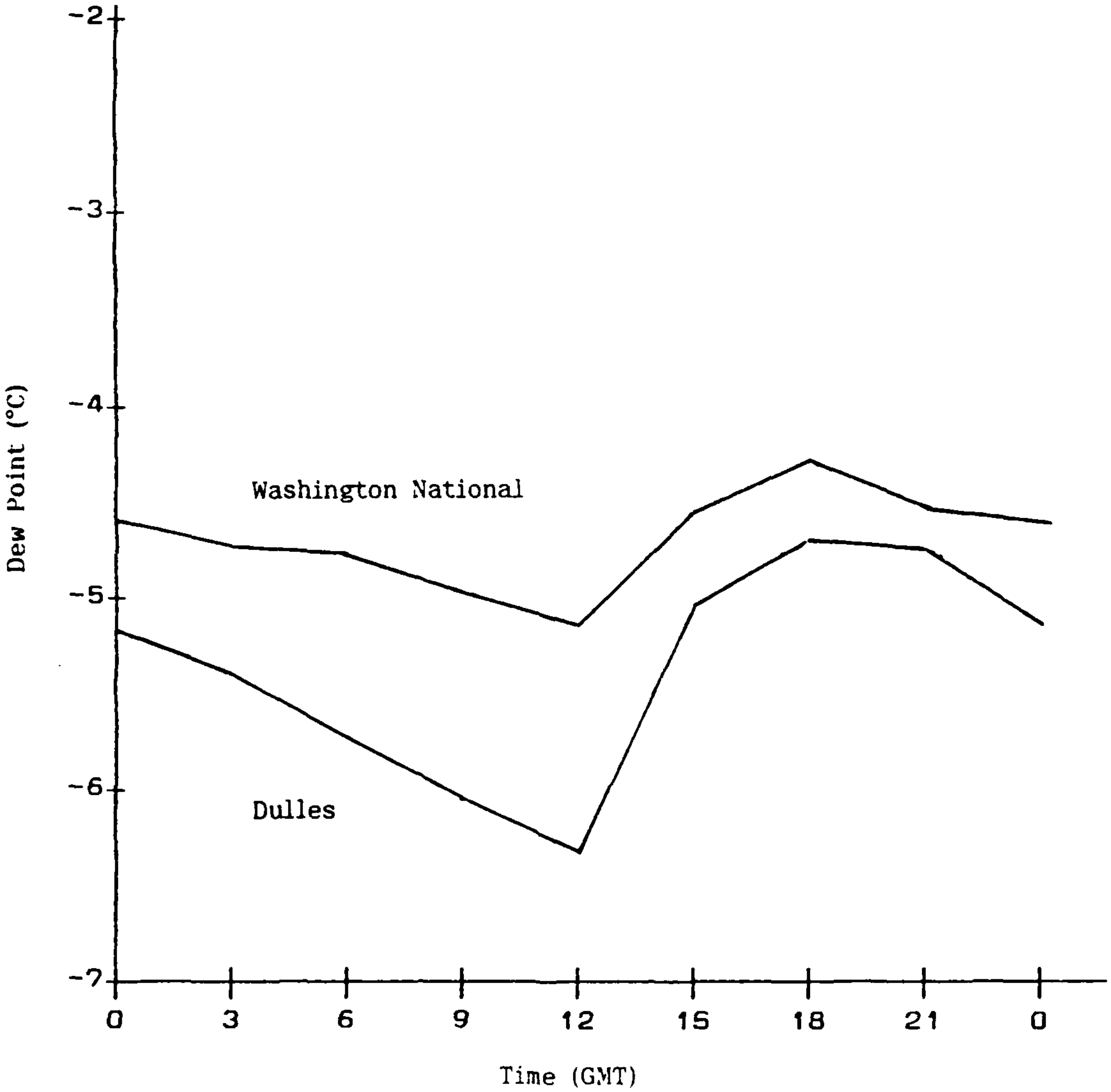

Figure 1. Diurnal variation of dew point at Washington National and Dulles International Airports during the winters 1962-1963 through 1980-1981.

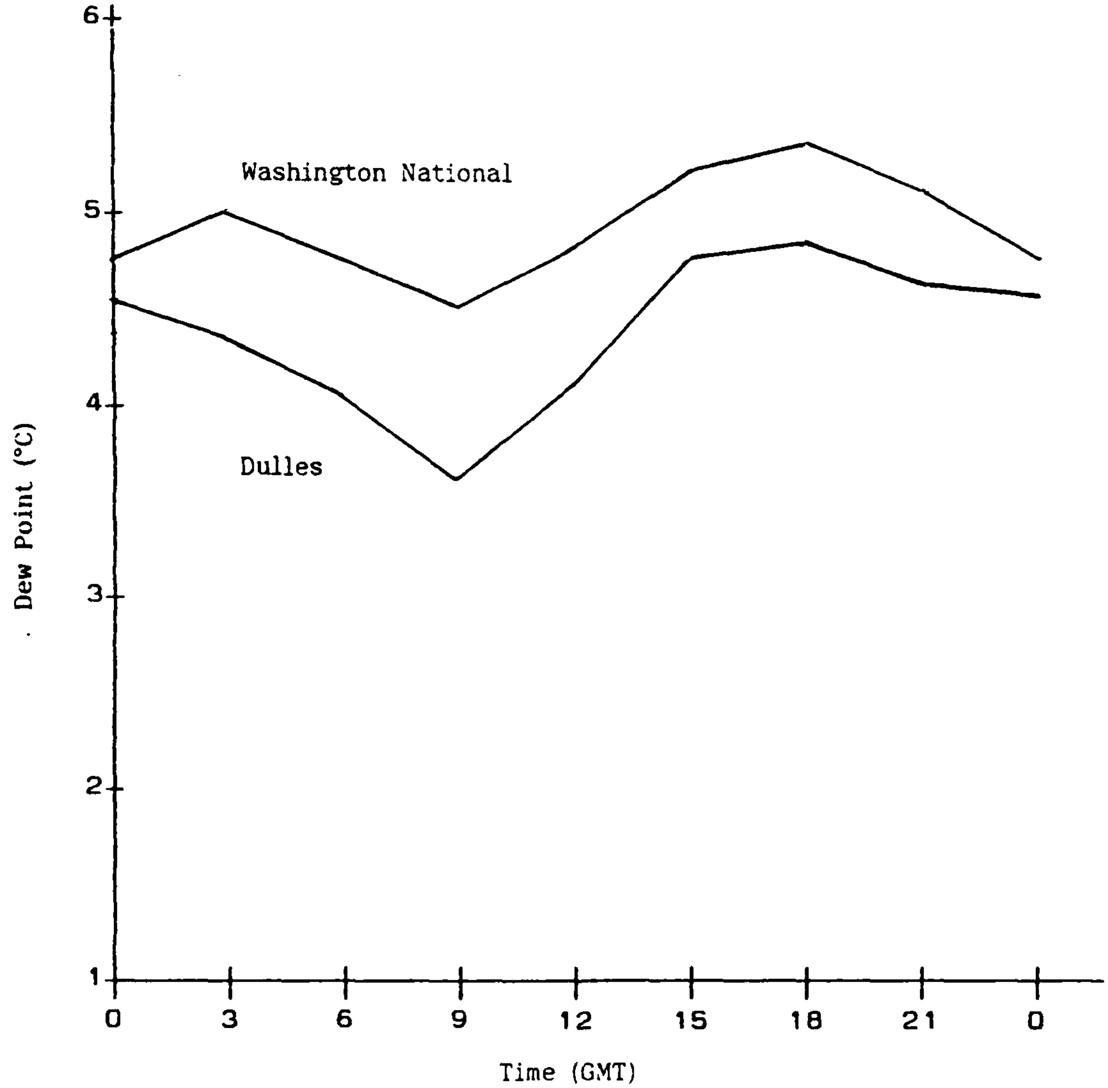

Figure 2. Diurnal variation of dew point at Washington National and Dulles International Airports during spring in the years 1963-1981.

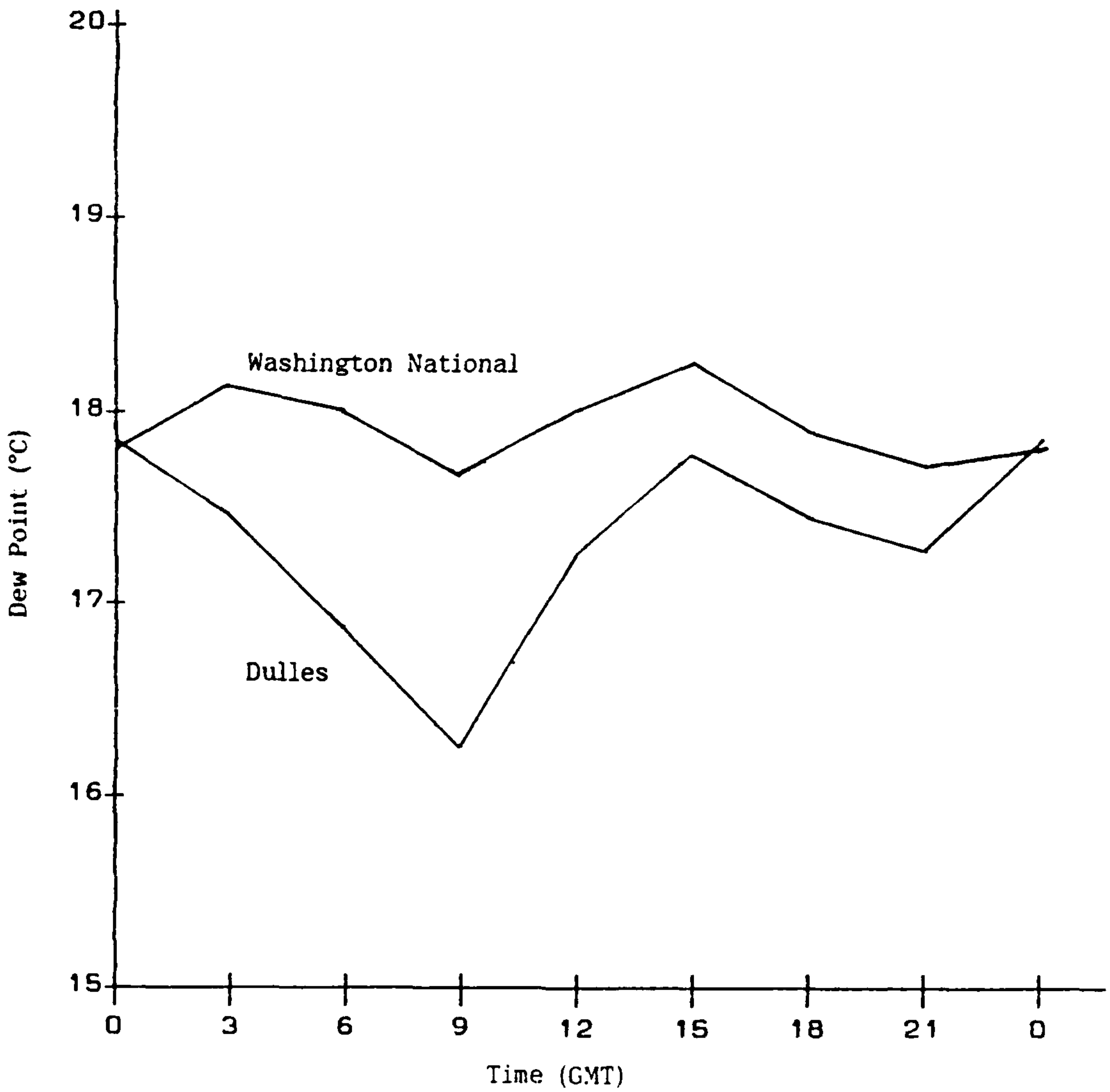

Figure 3. Diurnal variation of dew point at Washington National and Dulles International Airports during summer in the years 1963-1981.

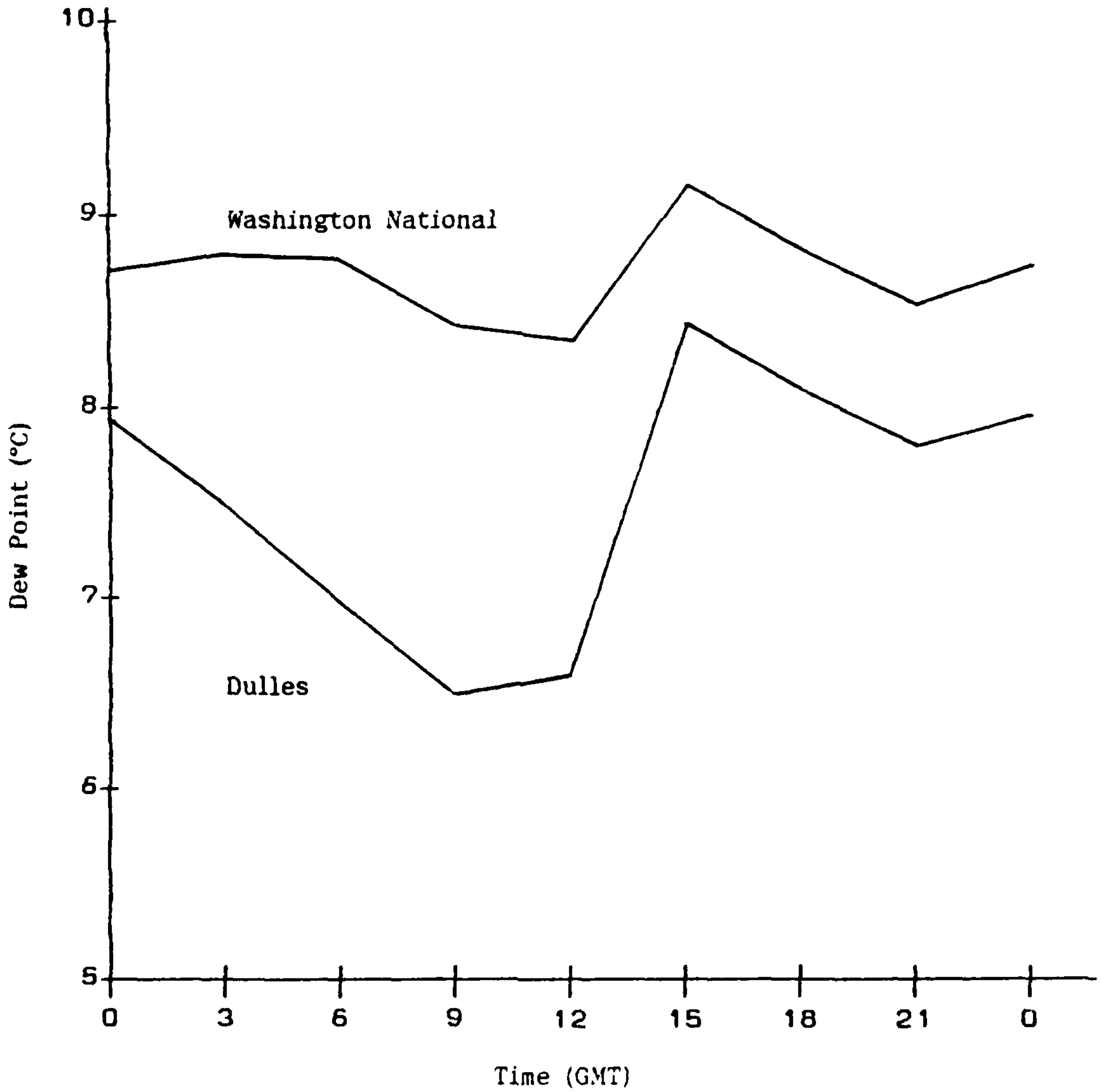

Figure 4. Diurnal variation of dew point at Washington National and Dulles Internal Airports during fall in the years 1963-1981.

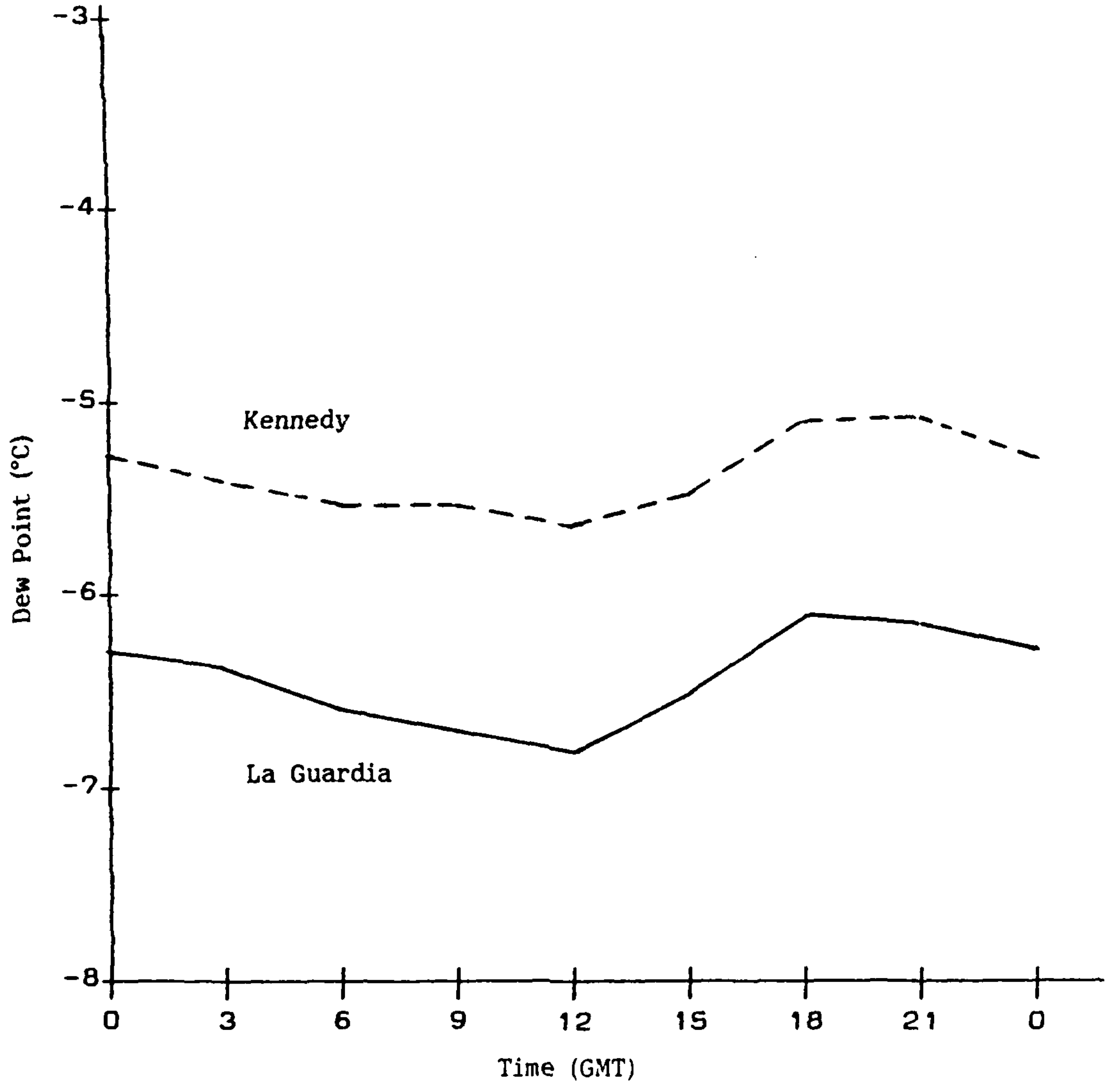

Figure 5. Diurnal variation of dew point at two New York sites during the winters 1965-1966 through 1980-1981.

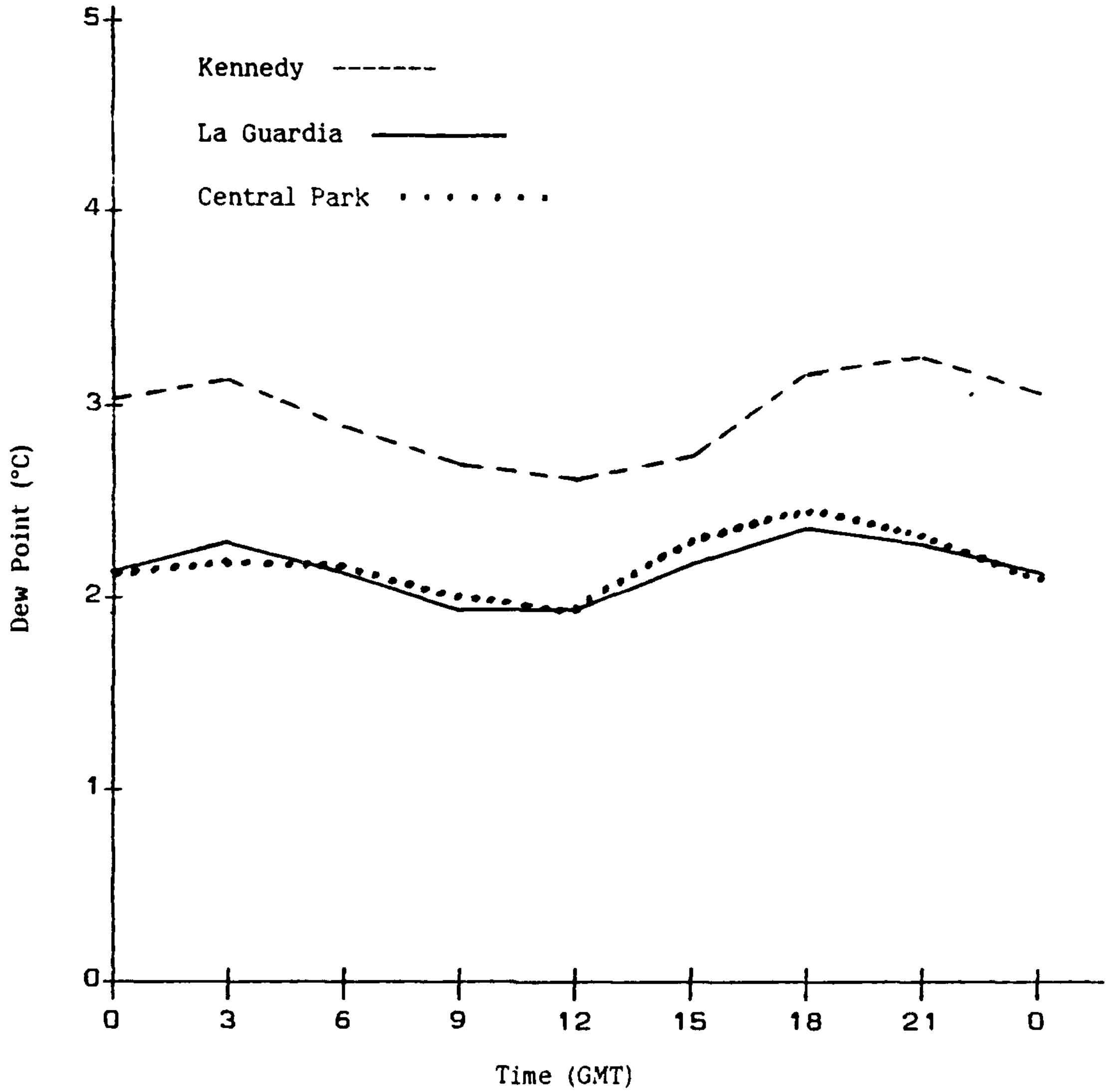

Figure 6. Diurnal variation of dew point at three New York sites during spring in the years 1965-1981

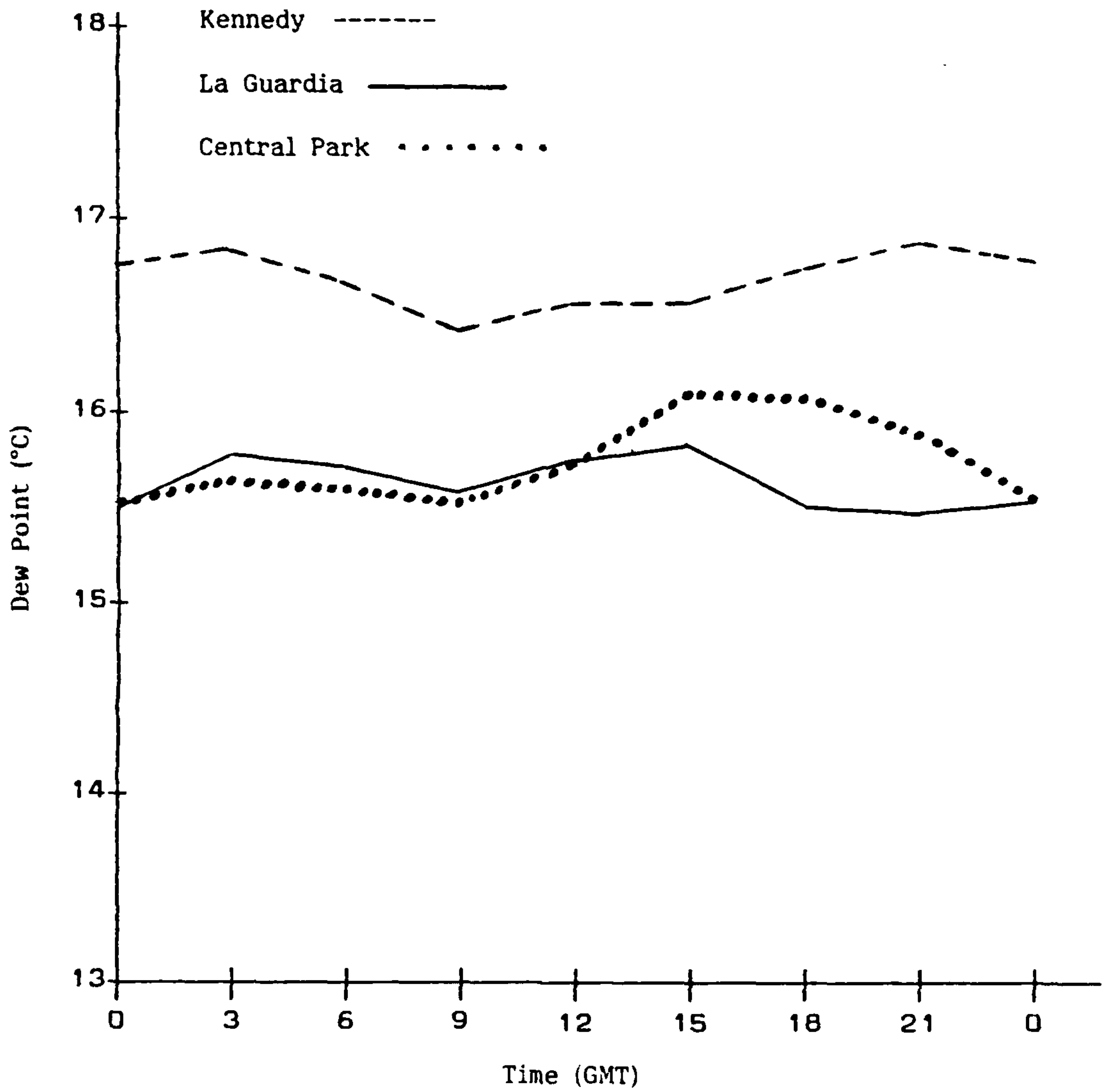

Figure 7. Diurnal variation of dew point at three New York sites during summer in the years 1965-1981.

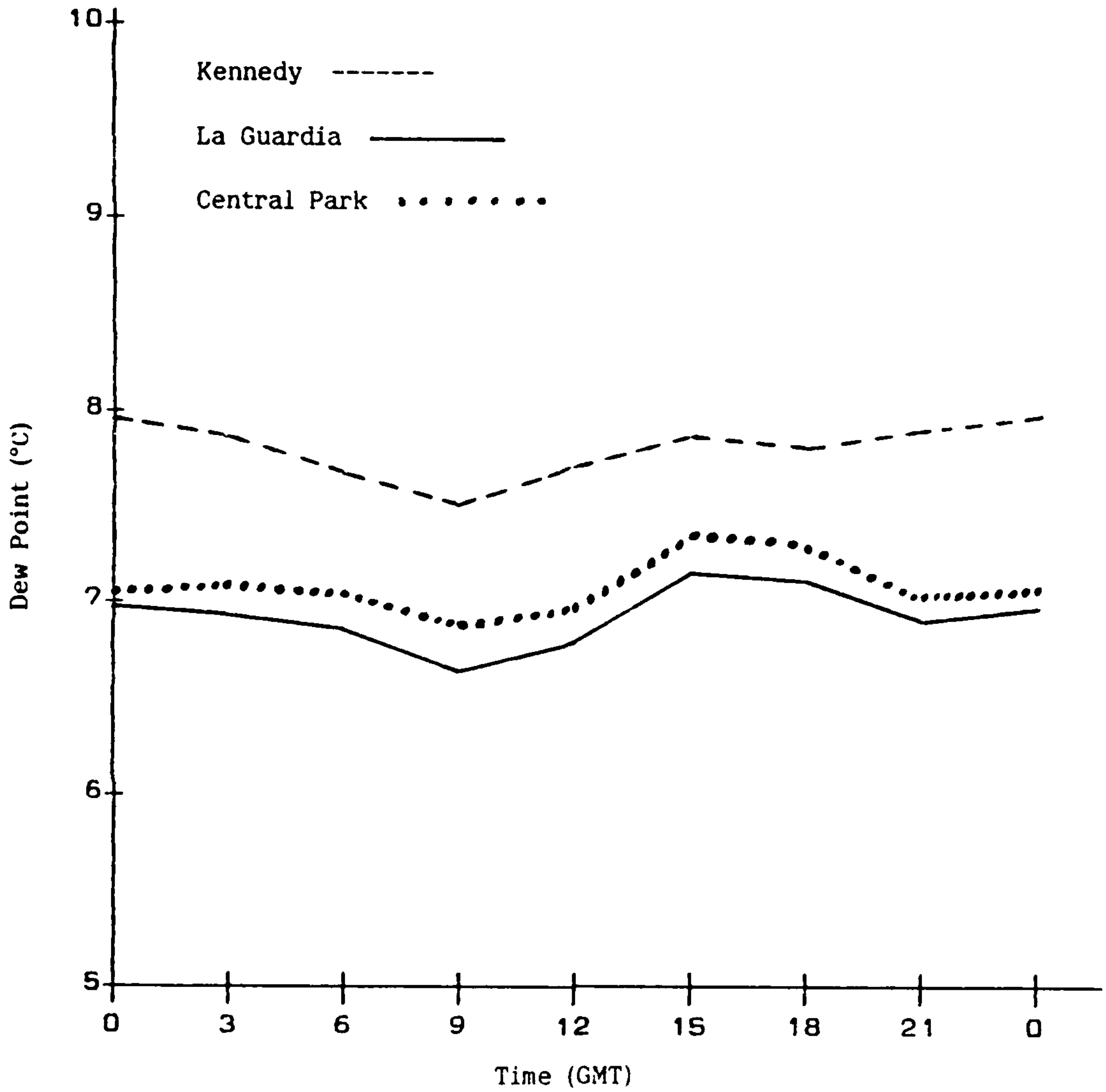

Figure 8. Diurnal variation of dew point at three New York sites during fall in the years 1965-1981.

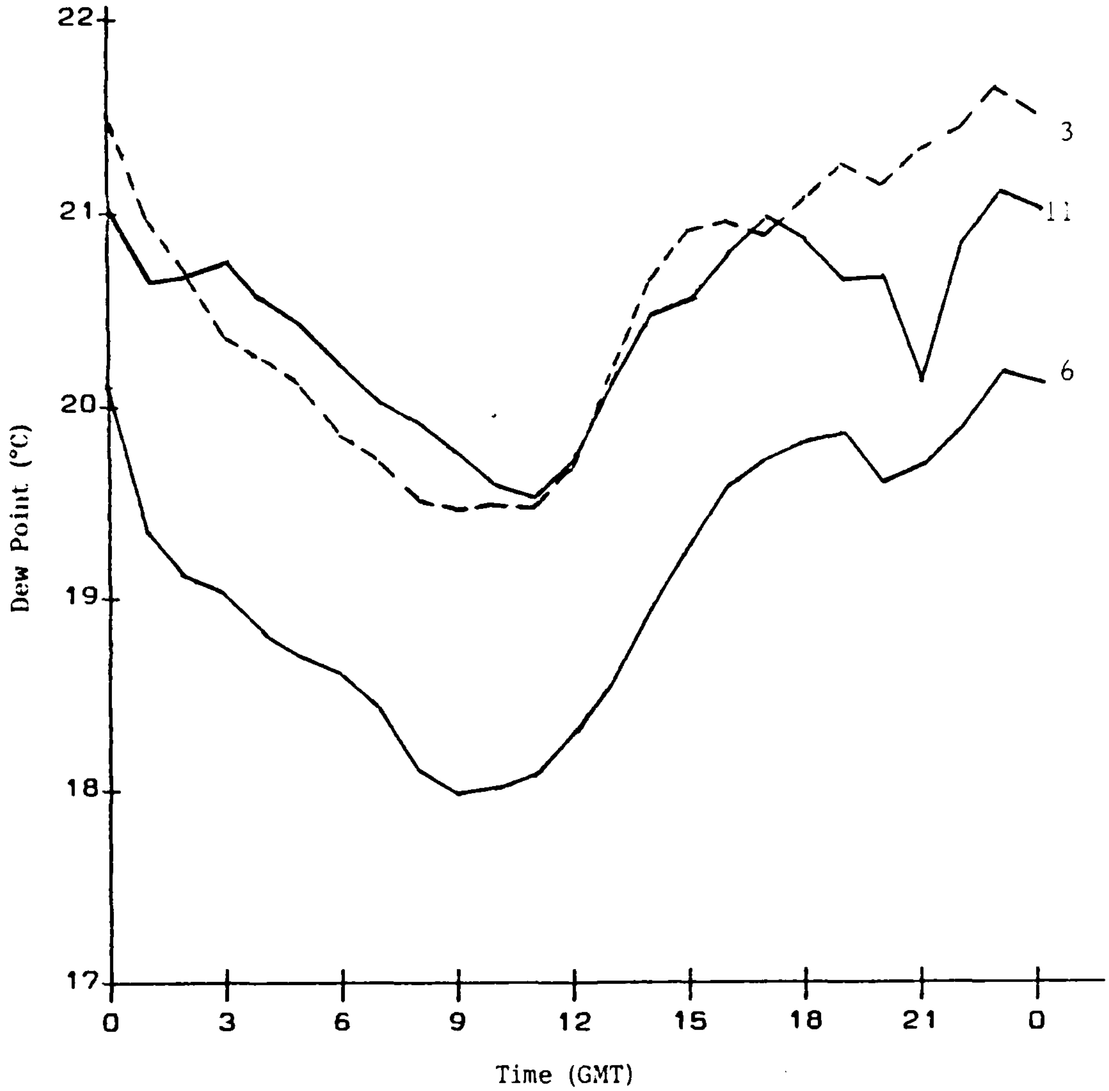

Figure 9. Diurnal variation of dew point at three PAM II stations during 1 - 8 June 1986.

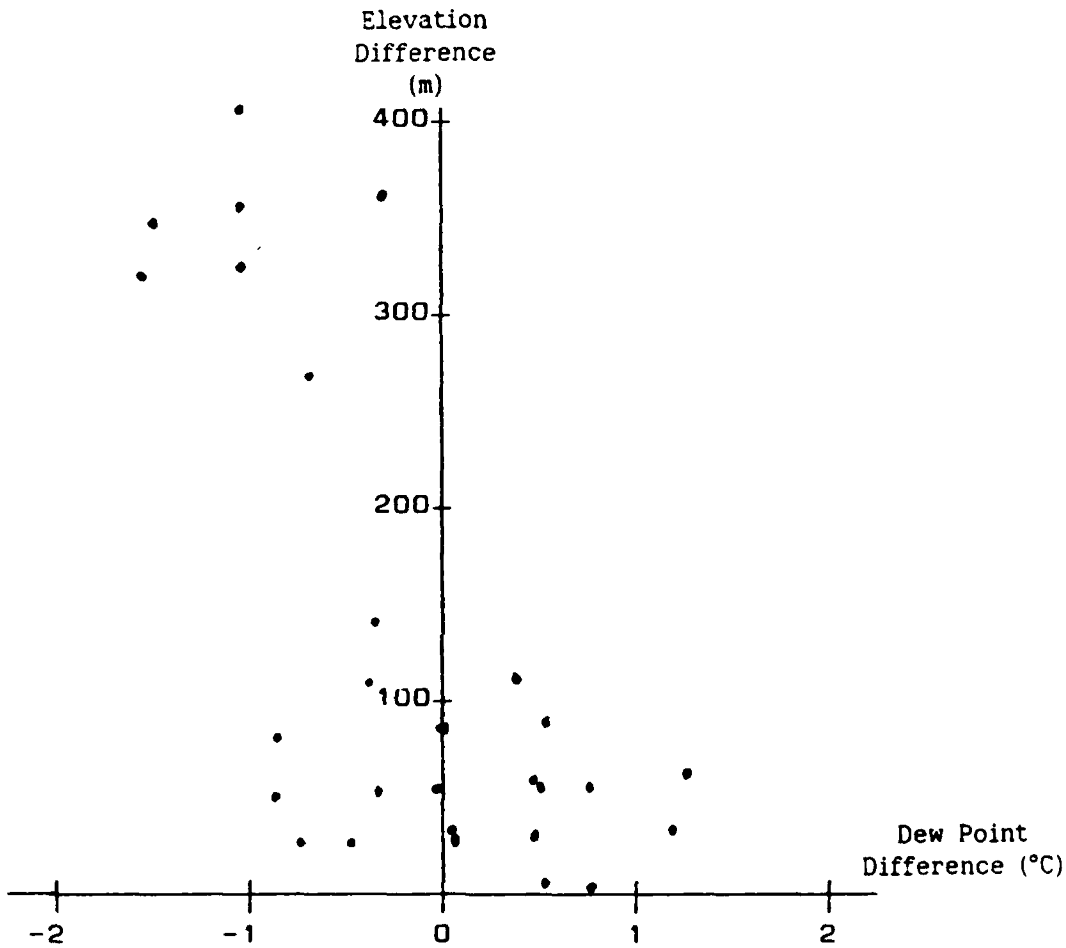

Figure 10. Graph to compare difference in elevation with difference in dew point during the time 2300-0159 GMT (1800-2059 CDT).

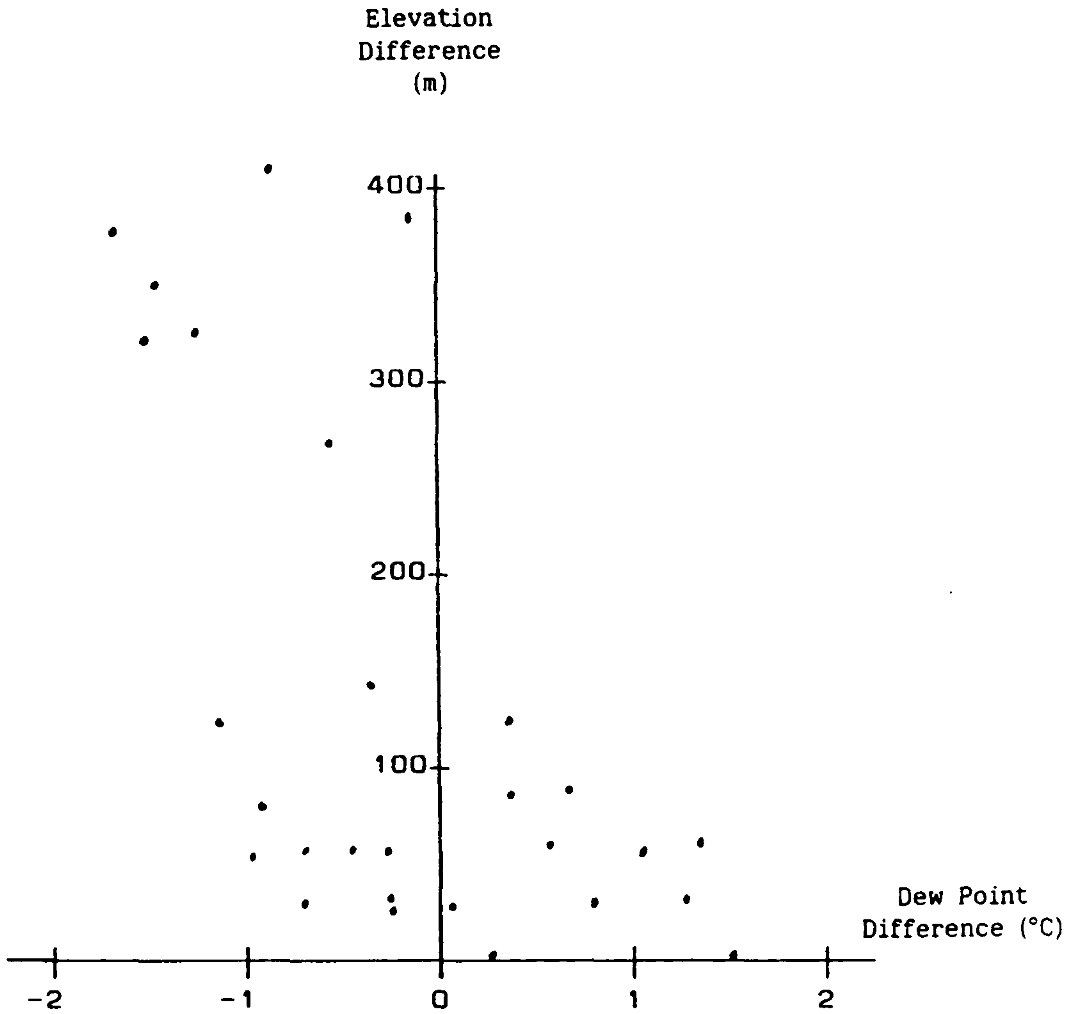

Figure 11. Graph to compare difference in elevation with difference in dew point during the time 0200-0459 GMT (2100-2359 CDT).

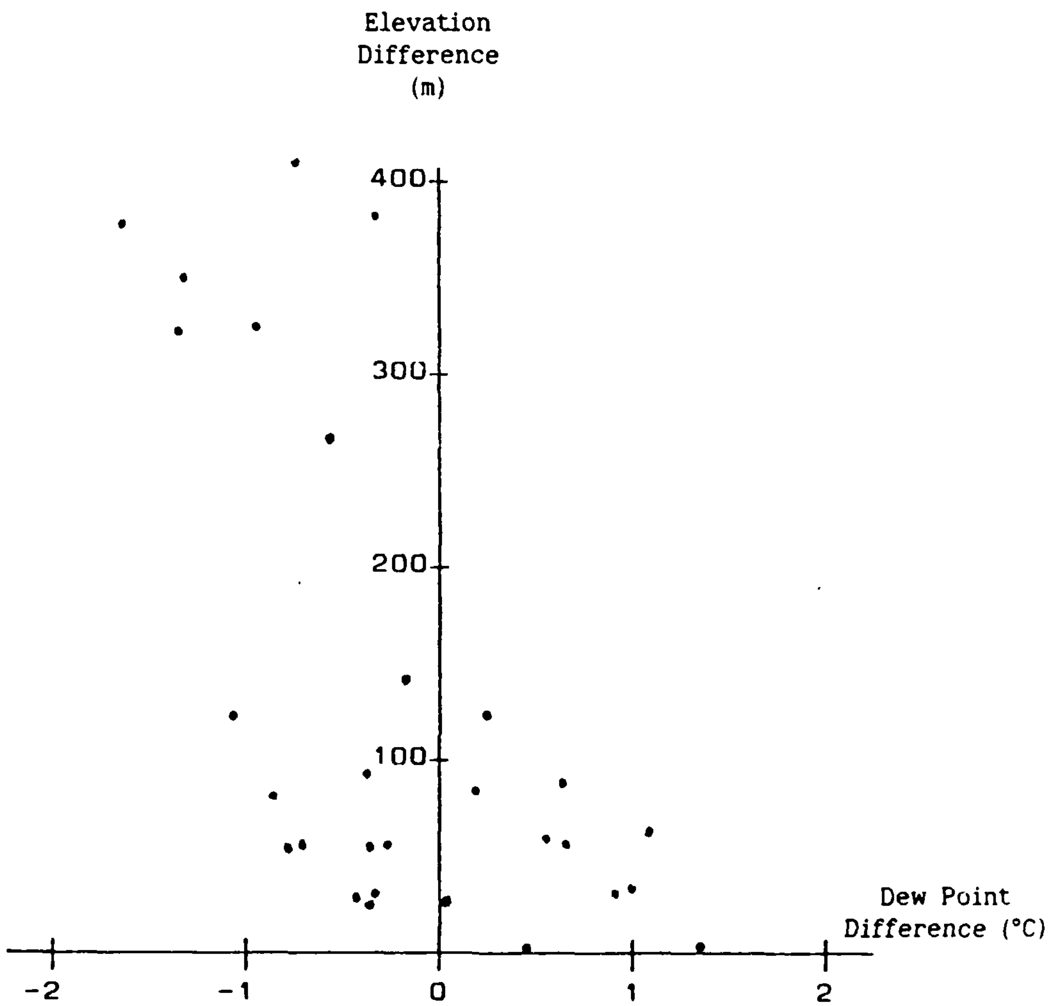

Figure 12. Graph to compare difference in elevation with difference in dew point during the time 0500-0759 GMT (0000-0259 CDT).

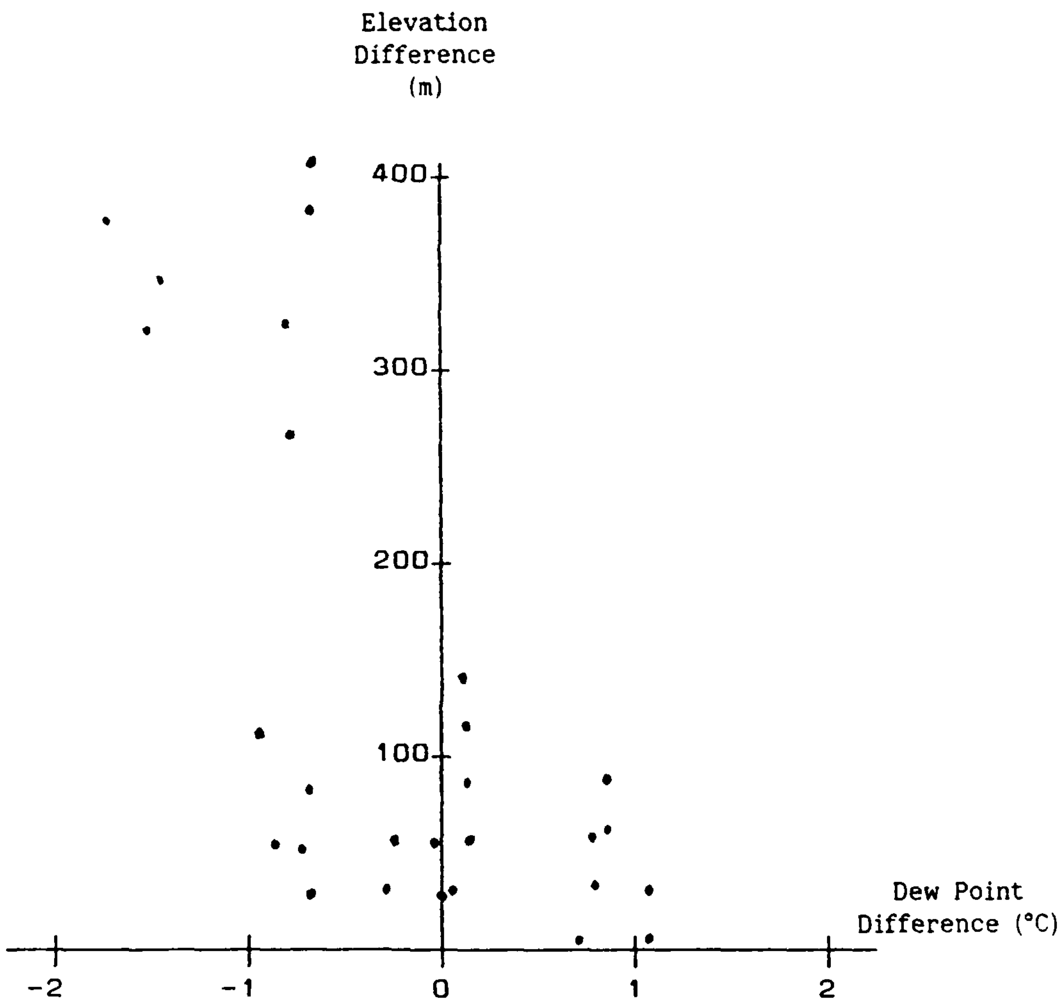

Figure 13. Graph to compare difference in elevation with difference in dew point during the time 0800-1059 GMT (0300-0559 CDT).

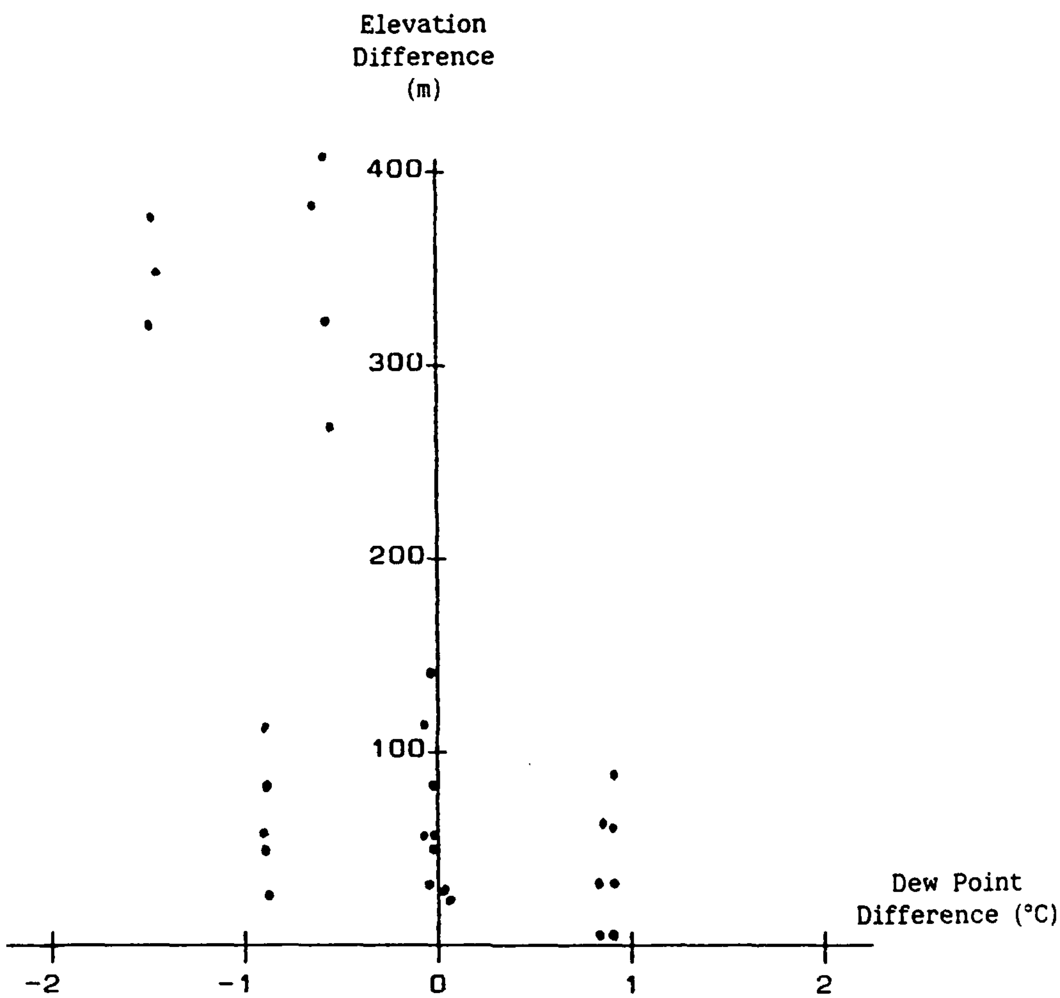

Figure 14. Graph to compare difference in elevation with difference in dew point during the time 1100-1359 GMT (0600-0859 CDT).

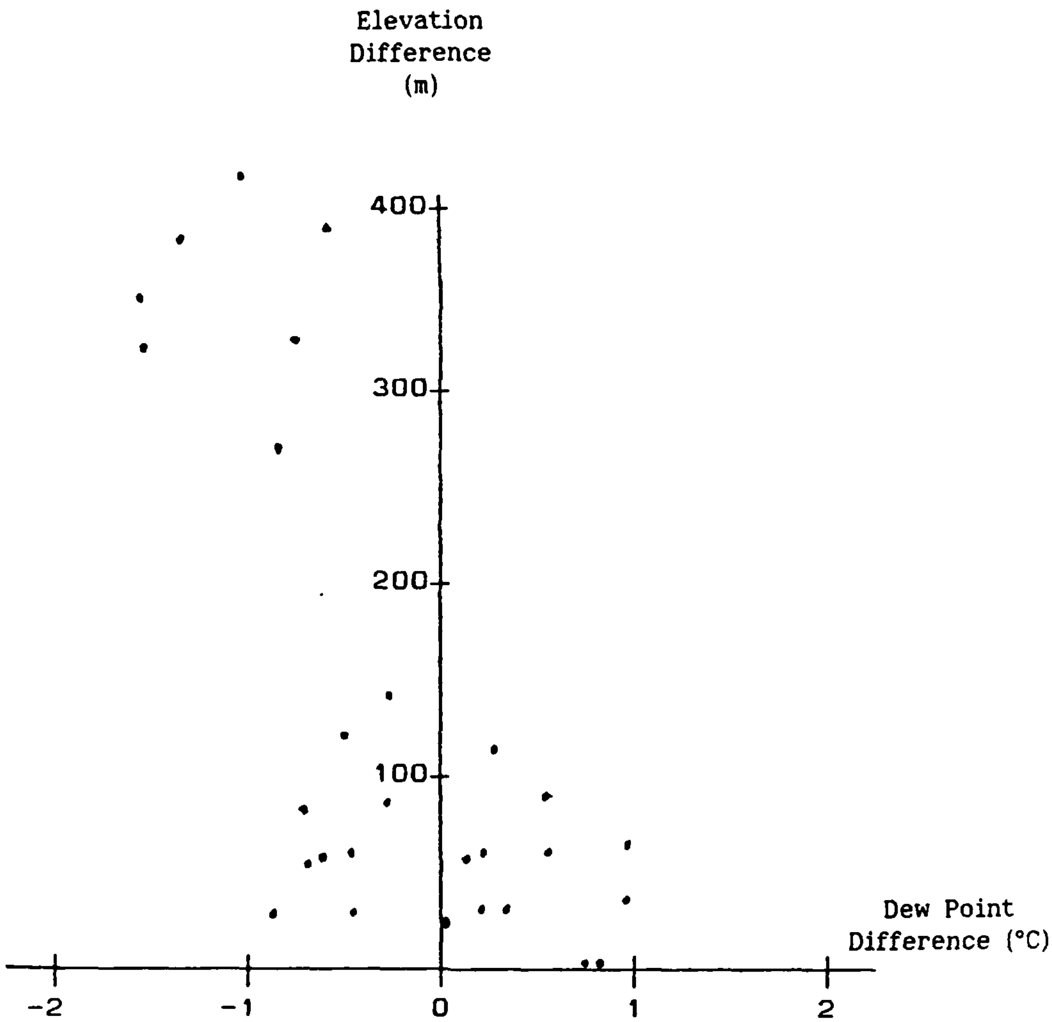

Figure 15. Graph to compare difference in elevation with difference in dew point during the time 1400-1659 GMT (0900-1159 CDT).

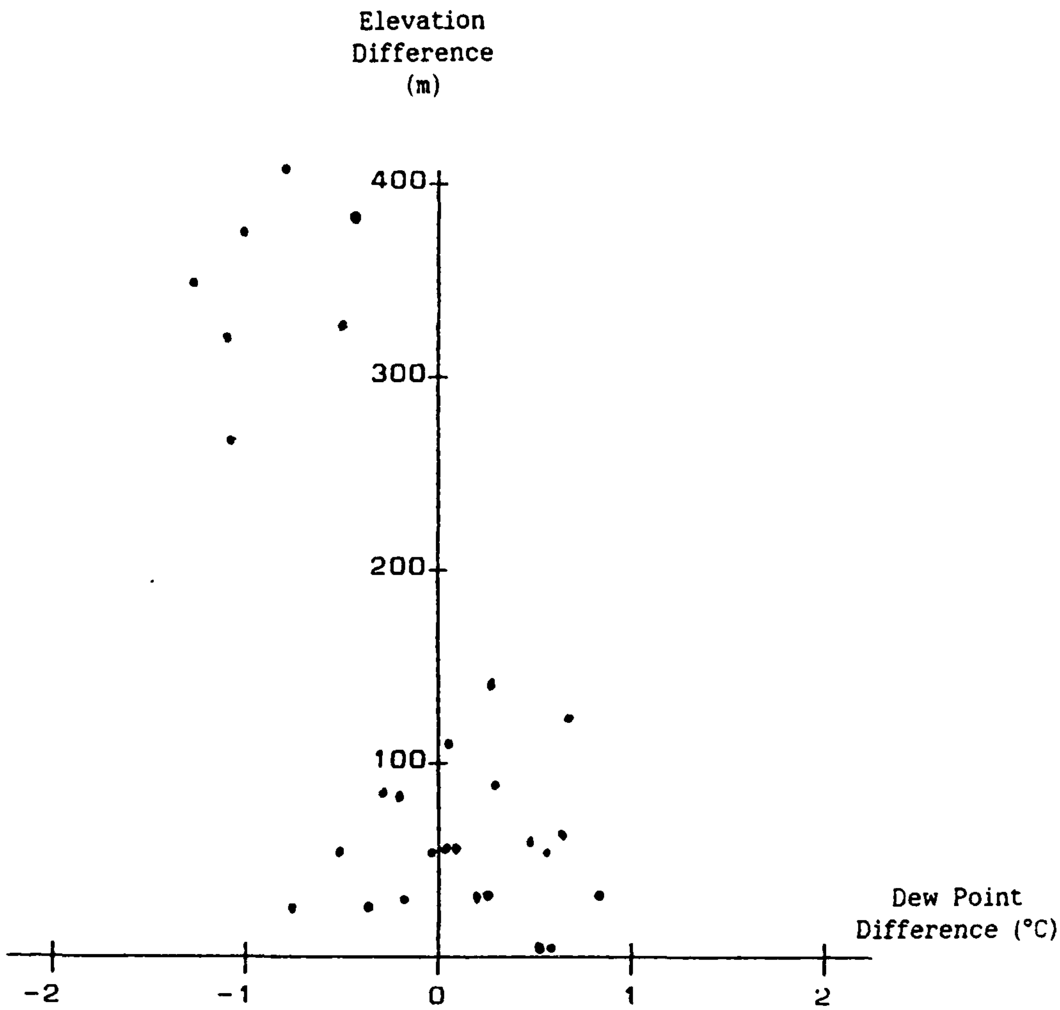

Figure 16. Graph to compare difference in elevation with difference in dew point during the time 1700-1959 GMT (1200-1459 CDT).

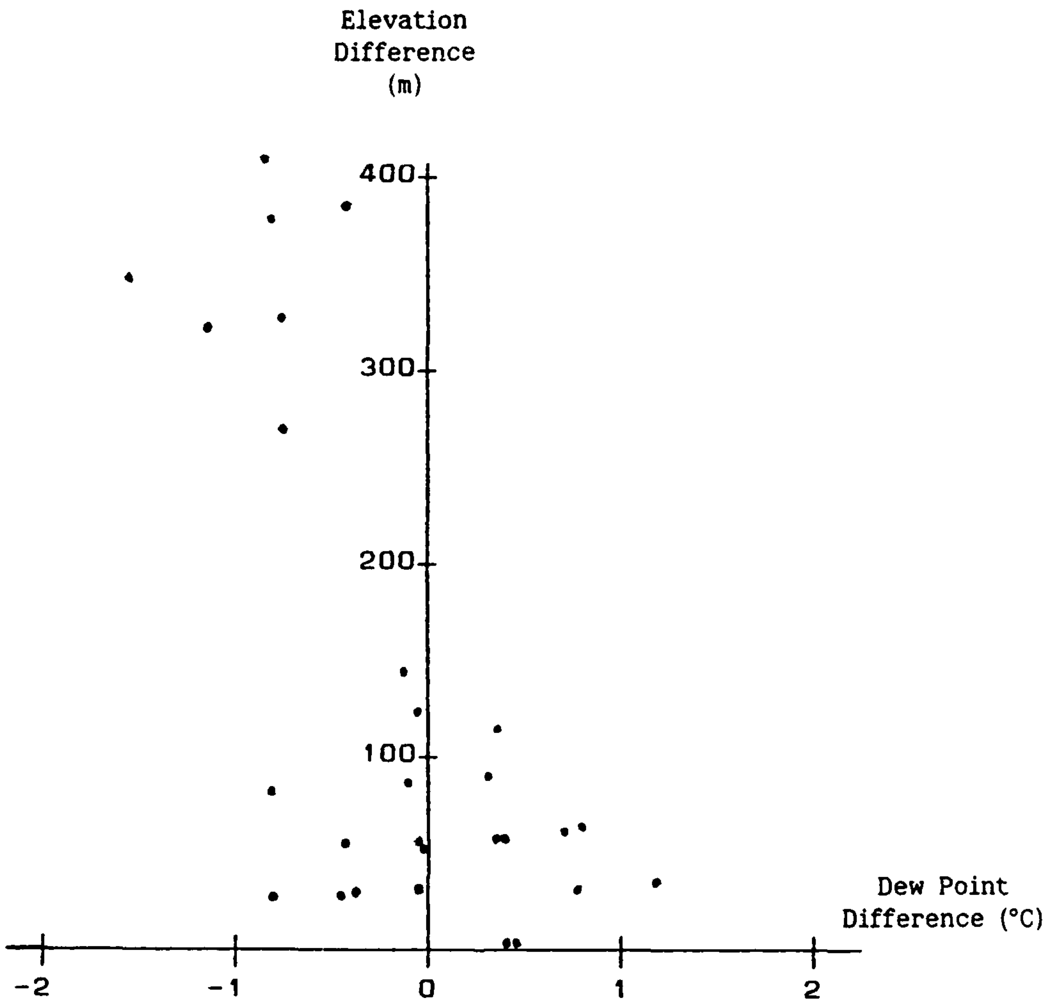

Figure 17. Graph to compare difference in elevation with difference in dew point during the time 2000-2259 GMT (1500-1759 CDT).

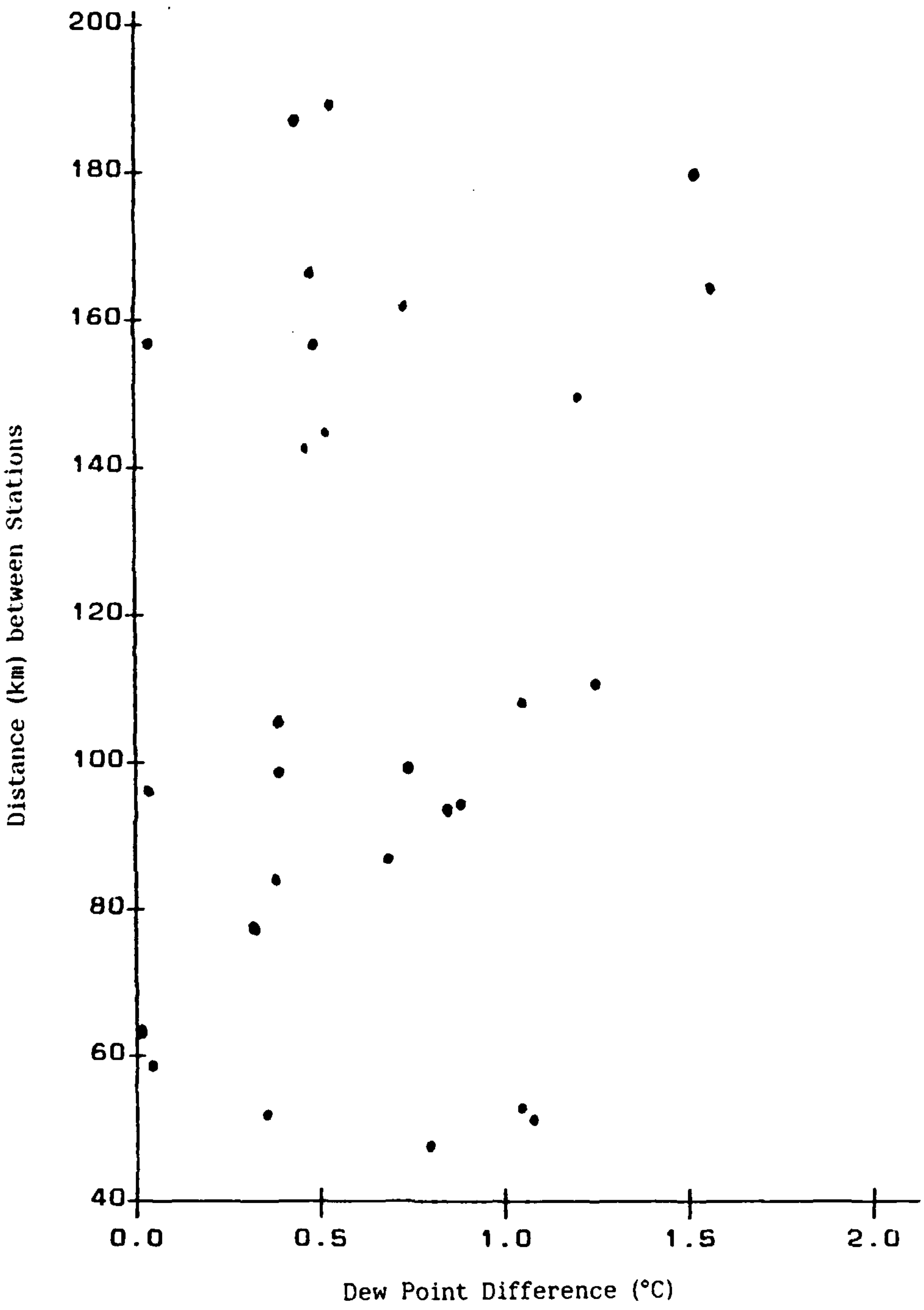

Figure 18. Graph to compare distance between stations with difference in dew point during the time 2300-0159 GMT (1800-2059 CDT).

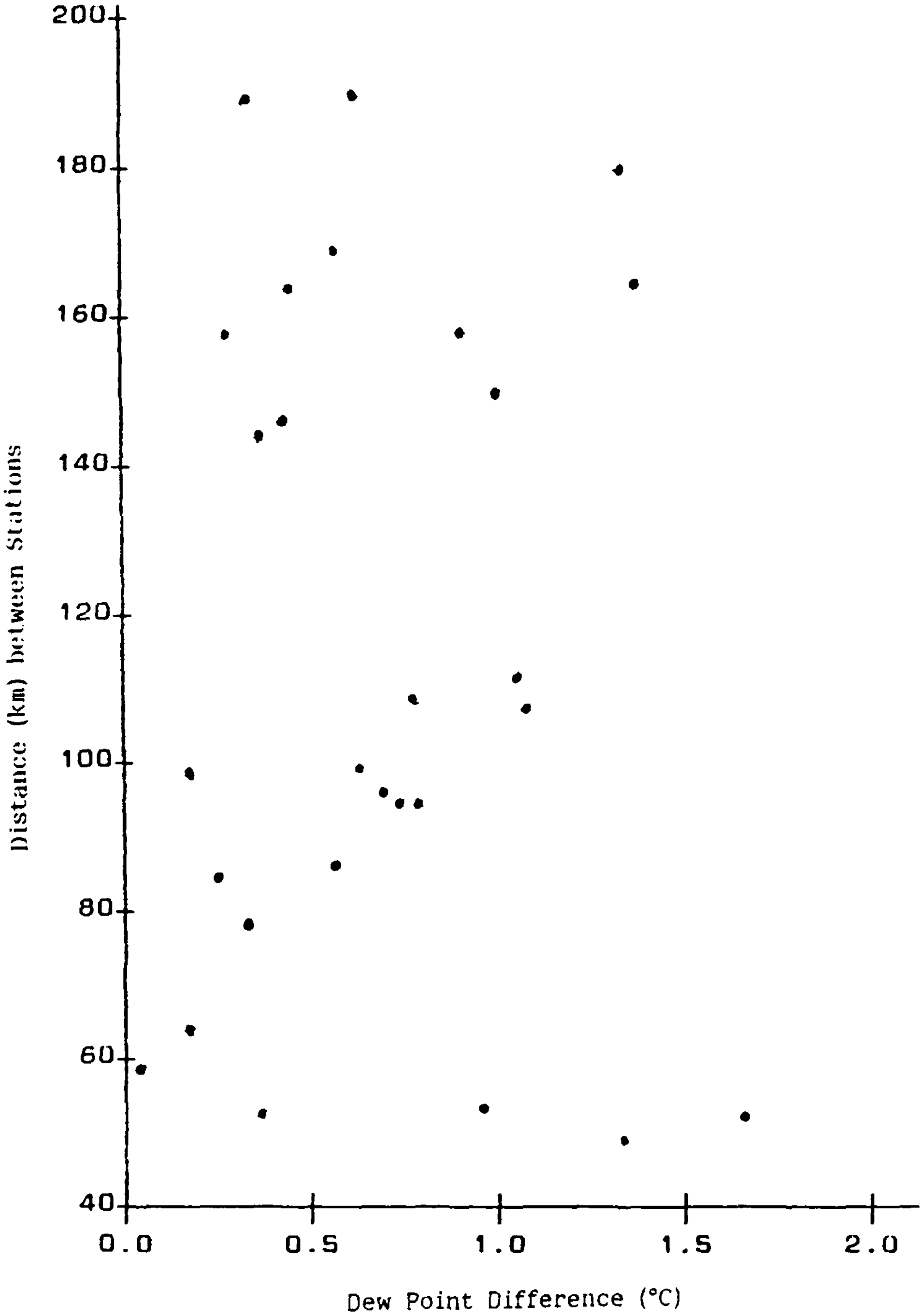

Figure 19. Graph to compare distance between stations with difference in dew point during the time 0500-0759 GMT (0000-0259 CDT).

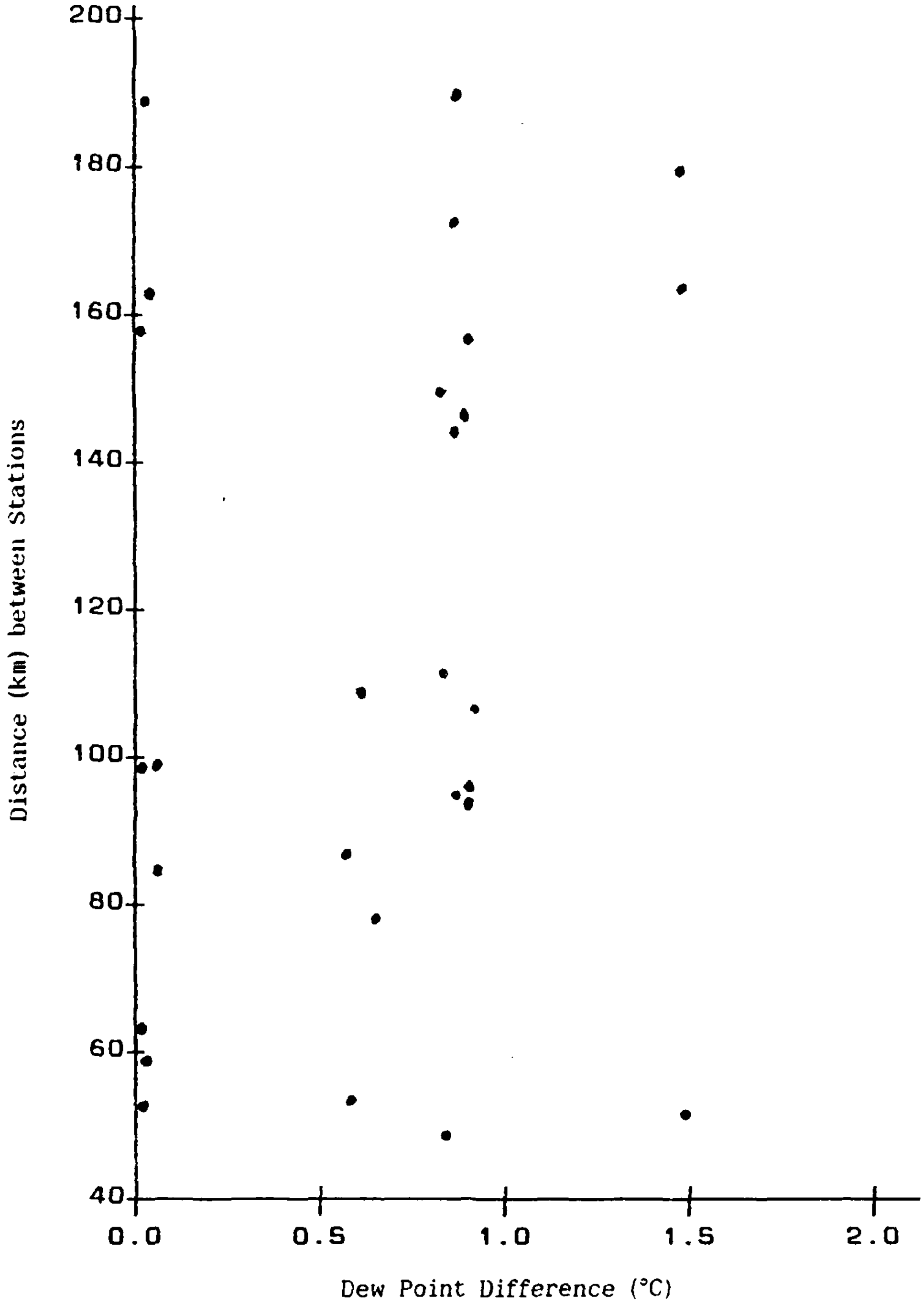

Figure 20. Graph to compare distance between stations with difference in dew point during the time 1100-1359 GMT (0600-0859 CDT).

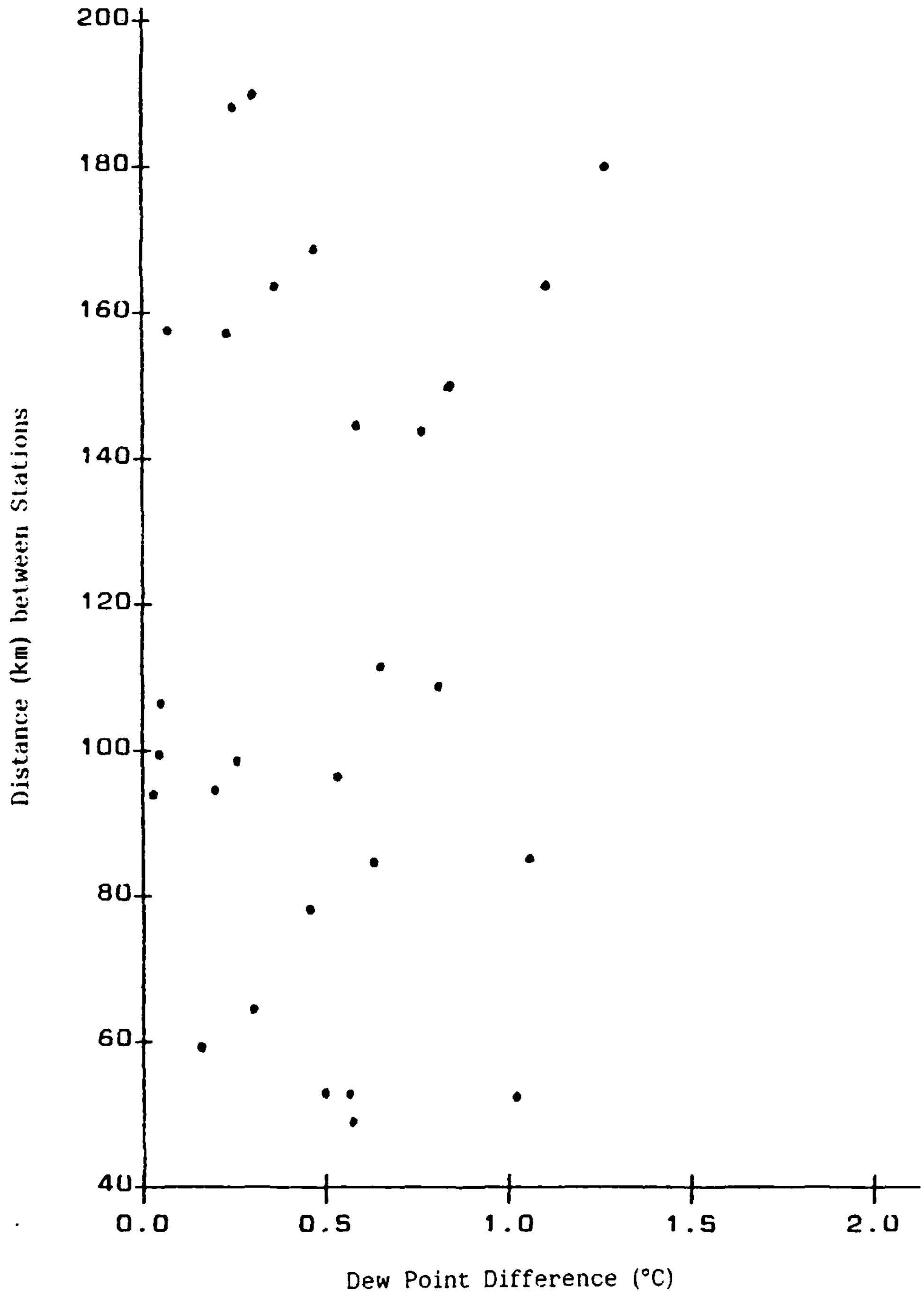

Figure 21. Graph to compare distance between stations with difference in dew point during the time 1700-1959 GMT (1200-1459 CDT).

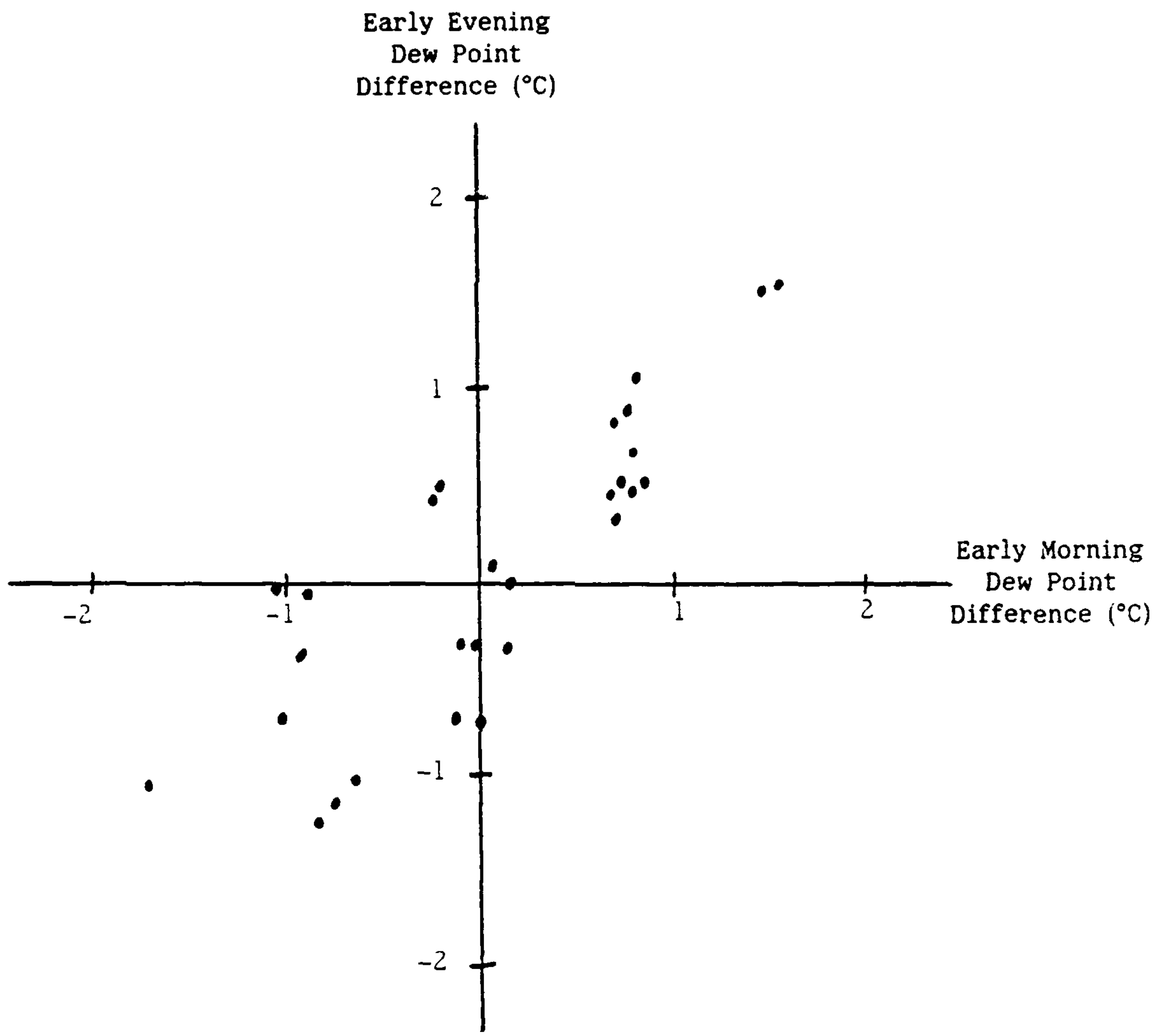

Figure 22. Comparison of dew point differences at pairs of stations during two different times of day.

TABLE 1. Locations and Elevations of Sites Where Dew Points Were Measured

Station	Latitude	Longitude	Elevation
1	34.5425°N	86.6017°W	186 m
2	34.6689°N	87.8094°W	247 m
3	35.1594°N	88.0600°W	219 m
4	35.2189°N	87.0217°W	300 m
5	35.4300°N	86.5092°W	244 m
6	35.0972°N	86.0900°W	567 m
7	36.0075°N	86.5217°W	159 m
11	34.6372°N	86.0903°W	189 m

TABLE 2. Distances Between Sites in Kilometers

	1	2	3	4	5	6	7	11
1	0.00	111.35	149.61	84.35	98.98	77.32	162.95	47.95
2	111.35	0.00	59.09	94.25	145.40	163.80	189.08	157.18
3	149.61	59.09	0.00	94.52	143.83	179.17	167.95	188.66
4	84.35	94.25	94.52	0.00	52.05	85.72	98.59	106.67
5	98.98	145.40	143.83	52.05	0.00	53.05	64.18	95.99
6	77.32	163.80	179.17	85.72	53.05	0.00	108.42	51.12
7	162.95	189.08	167.95	98.59	64.18	108.42	0.00	157.21
11	47.95	157.18	188.66	106.67	95.99	51.12	157.21	0.00

TABLE 3. Mean Dew Points (°C) for the Eight Days

Hr	1	2	3	4	5	6	7	11
1	19.77	21.07	21.00	20.12	20.64	19.36	20.30	20.69
2	19.40	20.71	20.67	19.89	20.39	19.09	19.95	20.67
3	19.11	20.42	20.37	19.35	20.22	19.02	19.81	20.75
4	18.96	20.33	20.25	19.32	20.02	18.81	19.83	20.57
5	18.94	20.11	20.09	19.21	19.76	18.66	19.59	20.41
6	18.82	19.97	19.85	19.10	19.50	18.60	19.35	20.21
7	18.92	19.73	19.71	19.11	19.28	18.42	19.02	20.02
8	18.79	19.55	19.51	18.97	18.97	18.09	18.83	19.92
9	18.67	19.53	19.45	18.77	18.83	17.97	18.66	19.75
10	18.63	19.50	19.47	18.69	18.66	18.00	18.60	19.59
11	18.67	19.52	19.46	18.66	18.61	18.05	18.46	19.53
12	18.89	19.70	19.65	18.74	18.77	18.28	18.86	19.73
13	19.30	20.13	20.17	19.24	19.29	18.56	19.39	20.11
14	19.48	20.55	20.63	19.69	19.67	18.93	19.91	20.47
15	19.95	20.88	20.89	20.06	20.07	19.26	20.44	20.55
16	20.14	21.02	20.95	20.62	20.24	19.59	20.50	20.80
17	20.27	20.96	20.90	20.94	20.46	19.74	20.56	20.96
18	20.19	20.94	21.07	20.75	20.37	19.81	20.64	20.84
19	20.28	20.79	21.24	20.92	20.09	19.85	20.60	20.66
20	20.00	20.88	21.16	20.70	20.16	19.60	20.49	20.67
21	20.28	20.83	21.34	20.28	20.47	19.69	20.60	20.14
22	20.19	21.02	21.42	20.46	20.85	19.89	20.78	20.84
23	20.47	21.55	21.64	20.74	20.95	20.17	21.03	21.09
0	20.30	21.62	21.49	20.80	21.12	20.10	21.40	21.02

TABLE 4. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 2300-0159 GMT

	1	2	3	4	5	6	7	11
1	0.00	1.23	1.19	0.37	0.72	-0.31	0.73	0.75
2	-1.23	0.00	-0.04	-0.86	-0.51	-1.54	-0.51	-0.48
3	-1.19	0.04	0.00	-0.82	-0.47	-1.50	-0.47	-0.44
4	-0.37	0.86	0.82	0.00	0.35	-0.68	0.36	0.38
5	-0.72	0.51	0.47	-0.35	0.00	-1.03	0.00	0.03
6	0.31	1.54	1.50	0.68	1.03	0.00	1.03	1.06
7	-0.73	0.51	0.47	-0.36	0.00	-1.03	0.00	0.03
11	-0.75	0.48	0.44	-0.38	-0.03	-1.06	-0.03	0.00

TABLE 5. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 0200-0459 GMT

	1	2	3	4	5	6	7	11
1	0.00	1.33	1.27	0.36	1.05	-0.18	0.70	1.50
2	-1.33	0.00	-0.06	-0.97	-0.28	-1.52	-0.63	0.17
3	-1.27	0.06	0.00	-0.91	-0.22	-1.46	-0.57	0.23
4	-0.36	0.97	0.91	0.00	0.69	-0.55	0.34	1.14
5	-1.05	0.28	0.22	-0.69	0.00	-1.24	-0.35	0.45
6	0.18	1.52	1.46	0.55	1.24	0.00	0.89	1.69
7	-0.70	0.63	0.57	-0.34	0.35	-0.89	0.00	0.80
11	-1.50	-0.17	-0.23	-1.14	-0.45	-1.69	-0.80	0.00

TABLE 6. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 0500-0759 GMT

	1	2	3	4	5	6	7	11
1	0.00	1.04	0.99	0.25	0.62	-0.33	0.43	1.32
2	-1.04	0.00	-0.05	-0.79	-0.42	-1.37	-0.61	0.28
3	-0.99	0.05	0.00	-0.74	-0.37	-1.32	-0.56	0.33
4	-0.25	0.79	0.74	0.00	0.37	-0.58	0.18	1.07
5	-0.62	0.42	0.37	-0.37	0.00	-0.95	-0.19	0.70
6	0.33	1.37	1.32	0.58	0.95	0.00	0.76	1.65
7	-0.43	0.61	0.56	-0.18	0.19	-0.76	0.00	0.90
11	-1.32	-0.28	-0.33	-1.07	-0.70	-1.65	-0.90	0.00

TABLE 7. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 0800-1059 GMT

	1	2	3	4	5	6	7	11
1	0.00	0.83	0.78	0.11	0.13	-0.68	0.00	1.06
2	-0.83	0.00	-0.05	-0.72	-0.70	-1.51	-0.83	0.23
3	-0.78	0.05	0.00	-0.67	-0.66	-1.46	-0.78	0.27
4	-0.11	0.72	0.67	0.00	0.01	-0.79	-0.11	0.94
5	-0.13	0.70	0.66	-0.01	0.00	-0.80	-0.12	0.93
6	0.68	1.51	1.46	0.79	0.80	0.00	0.68	1.73
7	0.00	0.83	0.78	0.11	0.12	-0.68	0.00	1.05
11	-1.06	-0.23	-0.27	-0.94	-0.93	-1.73	-1.05	0.00

TABLE 8. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 1100-1359 GMT

	1	2	3	4	5	6	7	11
1	0.00	0.83	0.81	-0.07	-0.06	-0.65	-0.05	0.84
2	-0.83	0.00	-0.02	-0.90	-0.89	-1.48	-0.88	0.01
3	-0.81	0.02	0.00	-0.88	-0.87	-1.46	-0.86	0.03
4	0.07	0.90	0.88	0.00	0.01	-0.58	0.03	0.91
5	0.06	0.89	0.87	-0.01	0.00	-0.59	0.01	0.90
6	0.65	1.48	1.46	0.58	0.59	0.00	0.60	1.49
7	0.05	0.88	0.86	-0.03	-0.01	-0.60	0.00	0.89
11	-0.84	-0.01	-0.03	-0.91	-0.90	-1.49	-0.89	0.00

TABLE 9. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 1400-1659 GMT

	1	2	3	4	5	6	7	11
1	0.00	0.96	0.96	0.27	0.14	-0.60	0.43	0.75
2	-0.96	0.00	0.01	-0.69	-0.82	-1.55	-0.53	-0.21
3	-0.96	-0.01	0.00	-0.70	-0.83	-1.56	-0.54	-0.21
4	-0.27	0.69	0.70	0.00	-0.13	-0.86	0.16	0.49
5	-0.14	0.82	0.83	0.13	0.00	-0.73	0.29	0.62
6	0.60	1.55	1.56	0.86	0.73	0.00	1.02	1.35
7	-0.43	0.53	0.54	-0.16	-0.29	-1.02	0.00	0.33
11	-0.75	0.21	0.21	-0.49	-0.62	-1.35	-0.33	0.00

TABLE 10. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 1700-1959 GMT

	1	2	3	4	5	6	7	11
1	0.00	0.65	0.82	0.62	0.06	-0.45	0.35	0.57
2	-0.65	0.00	0.17	-0.03	-0.59	-1.10	-0.30	-0.08
3	-0.82	-0.17	0.00	-0.20	-0.76	-1.27	-0.47	-0.25
4	-0.62	0.03	0.20	0.00	-0.57	-1.07	-0.27	-0.05
5	-0.06	0.59	0.76	0.57	0.00	-0.50	0.30	0.52
6	0.45	1.10	1.27	1.07	0.50	0.00	0.80	1.02
7	-0.35	0.30	0.47	0.27	-0.30	-0.80	0.00	0.22
11	-0.57	0.08	0.25	0.05	-0.52	-1.02	-0.22	0.00

TABLE 11. Mean Differences of Dew Points (°C) for the Eight Days During the Time Period 2000-2259 GMT

	1	2	3	4	5	6	7	11
1	0.00	0.76	1.15	0.33	0.34	-0.43	0.47	0.40
2	-0.76	0.00	0.39	-0.43	-0.42	-1.19	-0.29	-0.36
3	-1.15	-0.39	0.00	-0.82	-0.81	-1.58	-0.68	-0.75
4	-0.33	0.43	0.82	0.00	0.01	-0.75	0.14	0.07
5	-0.34	0.42	0.81	-0.01	0.00	-0.77	0.13	0.06
6	0.43	1.19	1.58	0.75	0.77	0.00	0.89	0.83
7	-0.47	0.29	0.68	-0.14	-0.13	-0.89	0.00	-0.07
11	-0.40	0.36	0.75	-0.07	-0.06	-0.83	0.07	0.00

REFERENCES

1. Stewart, D. A., and Essenwanger, O. M., 1982, "A Survey of Fog and Related Optical Propagation Characteristics." Reviews of Geophysics and Space Physics, Vol. 20, No. 3, August 1982, pp. 481-495.

2. Stewart, D. A., 1987, Attenuation of Visible Energy in a Polluted Atmosphere. US Army Missile Command Technical Report TR-RD-RE-87-04.

3. List, R. J., 1958, Smithsonian Meteorological Tables. Smithsonian Institute, Washington, DC.

4. Godske, C. L., Bergeron, T., Bjerknes, J., and Bundgaard, R. C., 1957, Dynamic Meteorology and Weather Forecasting. Published jointly by the American Meteorological Society of Boston and the Carnegie Institution of Washington.

5. Stewart, D. A., 1982, Urban Influences on Fog. US Army Missile Command Technical Report RR-83-1.

6. Arnold, J., Wilson, G., Williams, S., and McNider, R., 1986, Satellite Precipitation Cloud Experiment (Experiment Design Document). Atmospheric Sciences Laboratory, K. E. Johnson Research Center, UAH.

7. Stewart, D. A., 1986, Vertical Profiles of Temperature and Humidity Below 100 Meters. US Army Missile Command Technical Report RD-RE-86-6.

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